INVESTIGATION OF EMISSION REDUCTION WITH SELECTIVE CATALYTIC REDUCTION (SCR) IN A D. I. DIESEL ENGINE

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ABSTRACT

Emission control is one of the biggest challenges in today's automobiles. The 3-way converter is expensive and cannot work under oxygen rich environment. The present investigation deals with the reduction of NO_x with selective catalyst reduction (SCR) in a 0.5 litres Kirloskar AV-1 Engine running under maximum load condition. In this study the emissions reduction potential of different catalyst has been investigated. For maximum engine load, the NO_x emission without SCR is maximum at 450 ppm, and it is reduced by 49% when catalyst zeolite and kaolin is used. With the catalyst magnesium and potassium, the emission reduction is 38%. For catalyst magnesium and potassium with diesel oxidation catalyst (DOC), the emission reduction is 31%. Similarly for maximum engine load, the Smoke emission without SCR is 18 HSU, and it was reduced by 33% when catalyst zeolite and kaolin is used. Likewise for catalyst zeolite and kaolin with DOC the emission reduces to 28% and for catalyst magnesium and potassium the emission is 17%. For maximum engine load the CO emission is 0.02 (% by volume.) without SCR and it is being reduced by 0.01 (% by volume) when SCR along with different catalysts are used.

Keywords: SCR, DOC, NO_X, Direct Injection, Hydro Carbon.

1. INTRODUCTION

The diesel engine cycle is the most efficient of the internal combustion power plants. NO_x and PM are two of the major pollutants in CI engines [1]. The biggest steps, toward a cleaner engine, have been achieved by optimization of the injection system with the electronic control of injection and use of turbo charger and after cooler technology. The recent developments of exhaust gas recirculation and variable turbo charging are other promising steps to cut down engine out emissions. Though it is very good if we remove them at their production stage it (engine modification, EGR, injection timing alteration etc), they affect the efficiency and performance of the engine. But, the after treatment processes such as SCR can be a trade of between better efficiency and reduced emissions. Exhaust after-treatment on diesel vehicles will be introduced and become mandatory in the coming years. Therefore the engine can be operated fuel efficiently, and the SCR system can reduce the emitted NO_x in most cases enough to meet legislation. However, NO_x concentration must be measured without delay from exhaust manifold to control amounts of urea solution. Spraying of aqueous urea solution in the upstream of the exhaust gas is an attractive solution. The aqueous urea dissociates into ammonia and carbon dioxide. The ammonia reacts with NO_x to produce harmless nitrogen gas and water vapour [2]. But carrying another chemical on-board is another problem. The SCR technology with urea as reducing agent has already been applied successfully to stationary applications and to mobile Diesel engines in applications such as ships and locomotives. Though, the SCR technology is three decade sold, it is still a developing technology. This method shows an excellent reduction in emissions and the reduction in efficiency of the engine is negligible. This paper reports a fully developed after-treatment process based on injection of urea in the upstream of the exhaust gas. The Urea-SCR system was developed to meet the demand for low NO_x emissions without compromising the engine efficiency from the existing diesel vehicles. The thermal decomposition, hydrolysis, and chemical reactions of urea solution before converter can be described as following [3, 4 & 5]:

The evaporation of urea solution:

$$(NH_2)_2CO_{(aq)} \longrightarrow (NH_2)_2CO_{(s)} + H_2O_{(g)} \tag{1}$$

The thermal decomposition of urea:

$$(NH_2)_2CO_{(s)} - - \rightarrow NH_{3(g)} + HNCO_{(g)} \tag{2}$$

The hydrolysis of hydrocyanic acid:

$$HNCO_{(g)} + H_2O_{(g)} - - \rightarrow NH_{3(g)} + CO_{2(g)} \tag{3}$$

2. PREPARATION OF CATALYST

The Supporting channels were first coated with potassium sulphate/magnesium sulphate. It was then coated with salt (sodium silicate) and then the binder sodium chloride was added to the catalyst. The molecular weight of the catalyst is 122.06g. One litre of water mixes well with 122.06g of catalyst and 20ml of ammonium hydroxide is added. The mixture is allowed to dry for 2 days and kept in a furnace at the temperature of 700°C for several hours. The same procedure is carried out with the other catalysts Zeolite and Kaolin. In order to understand the NO_x reduction potential of material such as potassium sulphate, magnesium sulphate with ammonia SCR, investigations were conducted with different engine loads.

Equation (4) is used to find the quantity of ammonia to be injected for different emission levels of NO_x.

The quantity of ammonia to be injected is calculated using the following formula:

$$G_{exhaust} = \frac{\text{Mass 0f air} + (\text{Mass of Fuel} \times NO_x \text{ in ppm} \times \text{Mol.wt of } NO_x \times 2)}{\text{Mol.Wt of air} \times \text{power per load}} \quad (4)$$

Ammonia- (1 to .9) where $\frac{NH_3}{NO_x} = \alpha$

$G_{exhaust} = (1000 \times 3600) \div 10^6$

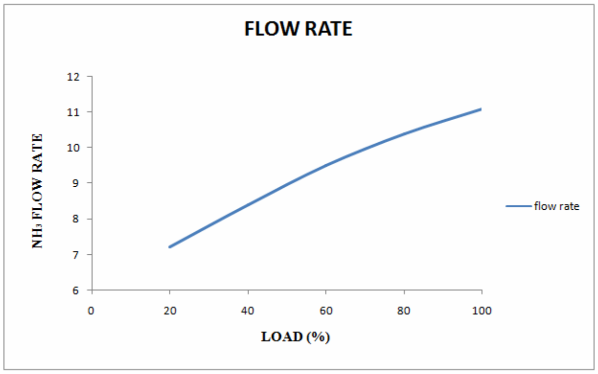

Figure-1. Mass flow rate of ammonia Vs load.

Figure-1 shows the ammonia flow rate required for different loads of the engine. Hence it is an indicator of the required amount of ammonia required for different NO_x emission level. Figure-2 shows the constructional details of the catalyst used in the experimental investigation. The developed catalytic core has a porosity of 0.6.

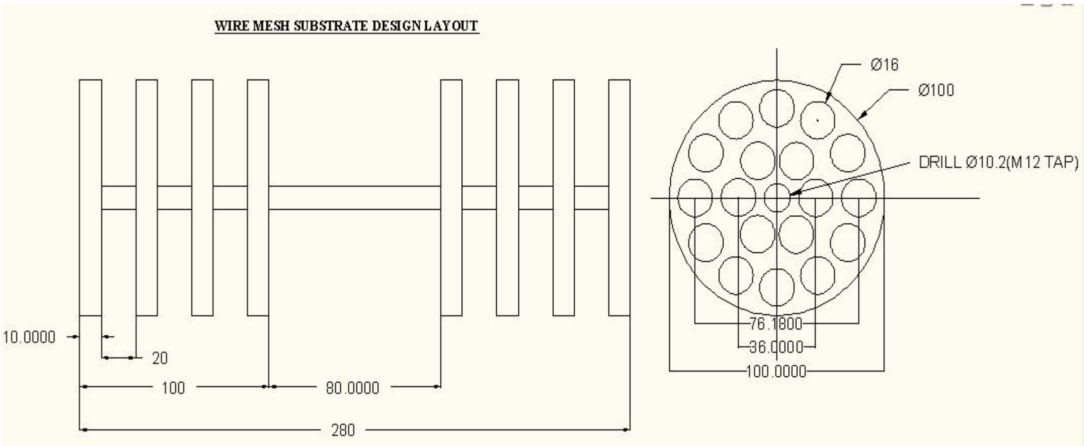

Figure-2. Layout of Catalytic Convertor.

3. EXPERIMENTAL SETUP

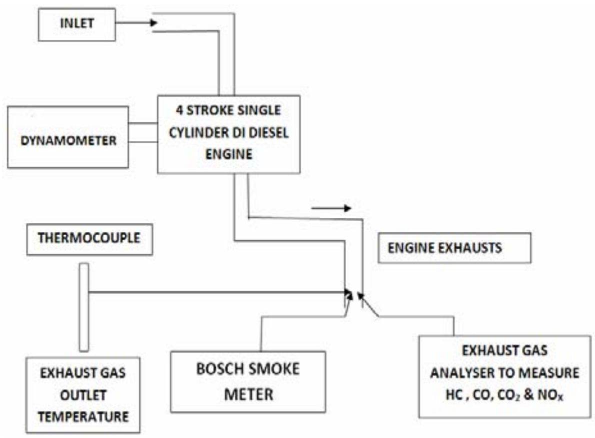

Figure-3. Experimental setup line diagram.

The engine used for the present investigation is kirloskar AV-1, single cylinder, four stroke, constant speed, vertical, water cooled, high speed compression ignition diesel engine. The kirloskar Engine is mounted on the ground. The test engine was directly coupled to dynamometer for loading the engine. The liquid fuel flow rate was measured on a volumetric basis using a burette and a stopwatch. AVL smoke meter was used to measure the smoke level. HORIBA five gas analyzer is used to measure NO_x, HC and CO emissions from the engine. For the measurement of cylinder pressure, a pressure transducer was fitted on engine cylinder head and a crank angle encoder was used for the measurement of crank angle. The sound from the engine was measured by "Rion" sound level meter. The experimental setup line diagram is shown in Figure-3. The specifications of the engine are given in Table-1. Figure-4 shows the photographic view of the actual engine setup.

Figure-4. Photographic view of engine setup.

Table-1. Engine specification.

Type	**Single cylinder, vertical, water cooled, four stroke, Kirloskar AV-1 diesel engine**
Bore	80mm
Stroke	110mm
Power	3.7 kw
Speed	1500rpm
Loading device	Swing field dynamometer

4. RESULTS AND DISCUSSIONS

In order to find the emission characteristics from the engine, baseline readings were measured without any after treatment system for the load ranging from no load to full load. Two set of experiments were carried out involving pure Urea SCR and Urea SCR with Diesel Oxidation Catalyst (DOC). The subsequent paragraph discusses the results obtained there in.

A. Brake Thermal Efficiency

There is usually a concern about the back pressure caused by the after treatment system. Figure-5 shows the variation of brake thermal efficiency with respect to load, for different catalyst concentration. From this evident there is apparently no variation in brake thermal efficiency due to the provision of after treatment system.

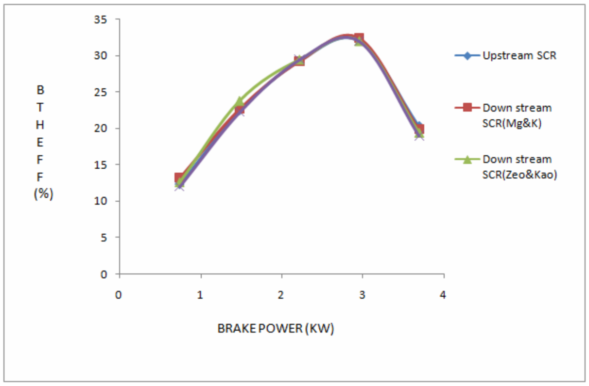

Figure-5. Brake thermal efficiency VS brake power.

B. NO_x Emission

Figure-6 shows the NO_x emission for various engine loads.

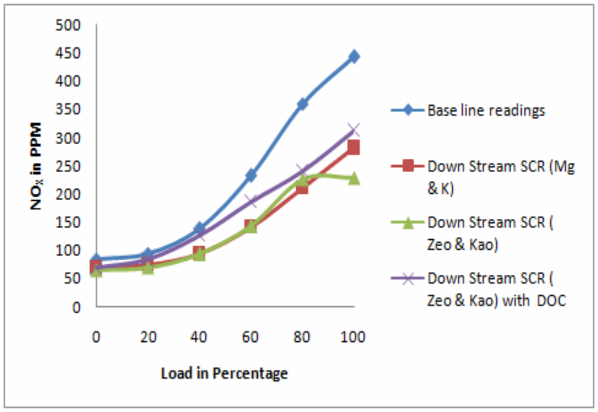

Figure-6. Effects of engine load on NO_x emission.

The removal of NO_x is especially difficult because of the excess oxygen associated in the diesel engine operation. It can be noted from Figure-6 that increasing engine load, oxides of nitrogen is also increased due to more oxygen content of fuel chemistry and better combustion quality of the fuel. For the maximum engine load, the NO_x emission of diesel engine without SCR is maximum at 450 ppm (Up Stream SCR) while there is a reduction of 49% of emission when SCR (zeolite-kaolin) is used. Further there is a reduction of 38% of emission when SCR (magnesium-potassium) is used. There is a reduction of only 31% of emission when SCR (zeolite-kaolin) with Diesel Oxidation Catalyst (DOC) is used.

C. HC Emission

It is noted from the Figure-7 that, when the engine load is increased, the hydrocarbon emission also increased without SCR (Up Stream SCR). This may be due to heterogeneous combustion of diesel engine. For maximum load HC emission is nearly 26 ppm. But with the introduction of SCR (zeolite-kaolin) or (magnesium and potassium) it reduces approximately by 42%. Similarly with SCR (zeolite-kaolin) with DOC the emission reduces to 38% (ppm).

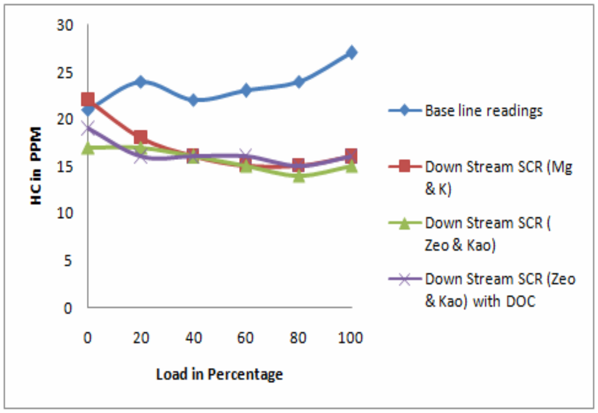

Figure-7. Effects of engine load on HC emissions.

D. CO Emission

It is noted from the Figure-8, when load is increased, the carbon mono oxide emission also increased due to heterogeneous combustion of diesel engine. This will lead to incomplete combustion of the fuel. When urea is injected the oxygen atom is removed from the reaction casing the exhaust gases without proper oxygen atom. For the maximum load, It is observed that for maximum load the CO emission of diesel engine without SCR setup is 0.02 (% by volume) whereas it is 0.01 (% by volume) with SCR (magnesium and potassium) with DOC setup.

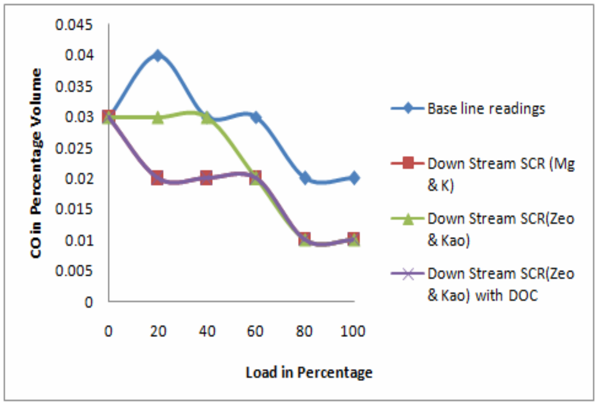

Figure-8. Effects of engine load in percentage on CO emissions.

E. CO_2 Emission

It is observed from the Figure-9 that the increasing load leads to a decrease in the CO_2 emissions. This is because, of complete combustion of fuel taking place. For the maximum load, the CO_2 emission of diesel engine without SCR setup is 2.8 (% by volume). When SCR is introduced (magnesium and potassium), the emission is 1.7 (% by volume). With SCR (zeolite and kaolin) the emission is 1.8 (% by volume), for DOC setup the emission is 1.9 (%.by volume).

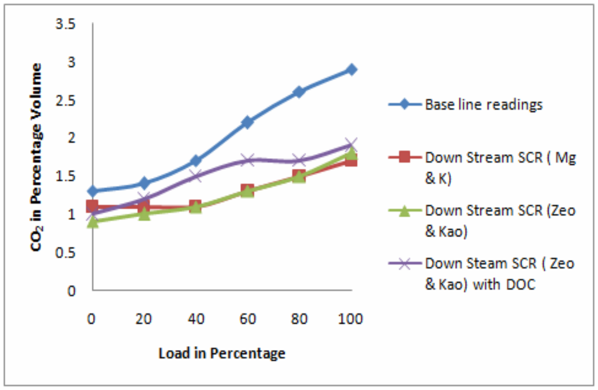

Figure-9. Effects of engine load in on CO_2 emissions.

F. Smoke Emission

It can be observed from the Figure-10, when the load is maximum the smoke level without SCR is 18 HSU. For test engine the emission reduces to 33% when SCR (zeolite -kaolin) is used. The emission is 28% when SCR (zeolite-kaolin) with DOC is used. Further there is a reduction of 17% of emission when Scr (magnesium and potassium) is used.

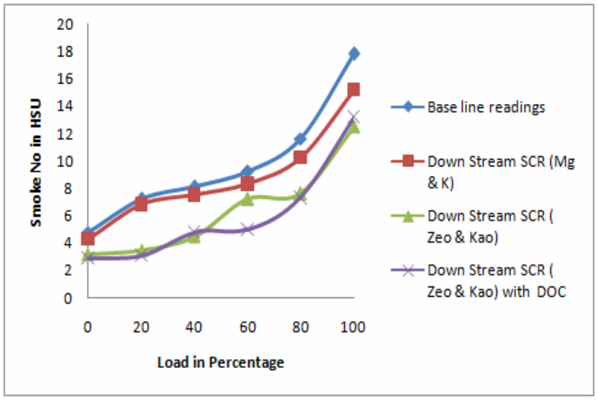

Figure-10. Effects of engine load in percentage with smoke emissions.

5. CONCLUSION

Experiments were conducted on a 0.5 litre DI Diesel engine to reduce the NO_x emission with after-treatment system with different low cost catalysts like zeolite-kaolin and potassium-magnesium with diesel oxidation catalyst. The results reveal that:

- There is apparently no variation in the brake thermal efficiency with after treatment system.
- The NO_x emission reduction is more efficient in zeolite - kaolin catalyst compared with potassium - magnesium.
- The introduction of diesel oxidation catalyst reduces the efficiency of the SCR system (zeolite - kaolin).
- For the two catalyst investigated the innovative materials are low in cost compared with convectional material and may be used with confidence in reducing the emissions primarily $NO_{x.}$

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